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ScienceDirect
Journal of Natural Gas Geoscience xx (2018) 1—13
http://www.keaipublishing.com/jnggs

Original research paper

Main controlling factors and distribution of high-quality deep dolomite reservoirs in typical cratonic basins in China

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Received 19 November 2017; revised 26 February 2018
Available online ■ ■ ■

Abstract

Deep dolomite in cratonic basins is an essential target for future natural gas exploration in China. Statistical analyses of major cratonic basins in China, such as the Sichuan, Tarim, and Ordos basins, indicate that the major types of deep dolomite (including granular dolomite, microbial dolomite, and crystalline dolomite) where fracture-vug and fracture-pore dominate the pore types. It is proposed that the favorable sedimentary microfacies is the base, whereas early dissolution is a necessary condition to form pores. Early dolomitization in penecontemporaneous and shallow burial periods is helpful to preserving the pores that developed during the penecontemporaneous period. Additionally, supergene karstification and structural fractures improve reservoir physical properties. It is pointed that sedimentary facies still control the referred high-quality deep dolomite reservoirs; they inherited more than being transformed in structure. The early sedimentary cycles, rather than depth, control their vertical distribution. Meanwhile, their lateral distribution is controlled by high-energy sedimentary facies belt rather than karstification. It is suggested that future exploration of high-quality deep dolomite reservoirs should target "both sides of an intra-platform rift" and low-middle parts of carbonate slopes.

Keywords: Cratonic basin; Deep dolostone; Dolomite reservoir; Sichuan basin; Tarim Basin; Ordos Basin

1. Introduction

Domestic and foreign scholars have conducted extensive research on the compaction of carbonate rocks and obtained pressure curves of depth and porosity since the 1960s. It is believed that the reservoir has a porosity of less than 3% at around 3500 m, which is not a favorable exploration target [1—12]. Petroliferous basins in China are dominated by superimposed basins where marine carbonate rocks are developed in the deep structure. The said basins are ancient and buried deeply. In this sense, there are no real "cratonic basins" in China. A real cratonic basin refers to the carbonate prototype basin developed prior the strong orogeny that started from the Proterozoic to the Mesozoic [13]. This paper highlights the "deeply-buried layers of craton basins" since the developmental scale of marine carbonate reservoirs in China is not constrained in shallow layers in superimposed basins. On the other hand, they are affected by the sedimentary pattern formed within the deep layers of cratonic basins. In recent years, exploration of deeply-buried carbonate rocks in cratonic basins (the burial depth of basins in eastern China is greater than 3500 m, wherein that in western China is deeper than 4500 m) have achieved breakthroughs. Puguang, Longgang,

This is English translational work of an article originally published in Natural Gas Geoscience (in Chinese). The original article can be found at: https://doi.org/10.11764/j.issn.1672-1926.2017.07.016.

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Peer review under responsibility of Editorial office of *Journal of Natural Gas Geoscience*.

https://doi.org/10.1016/j.jnggs.2018.04.003

Please cite this article in press as: J. Zhang, et al., Main controlling factors and distribution of high-quality deep dolomite reservoirs in typical cratonic basins in China, Journal of Natural Gas Geoscience (2018), https://doi.org/10.1016/j.jnggs.2018.04.003

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Yuanba, Anyue, and many more gas fields or gas play in the Permian reservoirs in western Sichuan Basin are further than 4500 m. In fact, the said fields are buried below 8000 m or even to 10000 m according to the burial history. Fortunately, due to the tremendous burial depth, the carbonate rocks still hold high porosity. The average porosity of the reservoir interval may range 5%—28% at maximum. Its exploration depth has far exceeded the lower limit of 3500 m [14]. The carbonate rocks in China's cratonic basins are distributed widely in a total area of over 300 × $10^4 km^2$. The deeply-buried reservoirs in cratonic basins are mainly developed in limestone karst reservoirs and dolomite reservoirs, especially the deeply-buried carbonate reservoirs where matrix pores are well developed with dolostone in lithology.

More than 95% of natural gas reserves in deeply-buried carbonate gas fields in the Sichuan Basin are concentrated in dolomite reservoirs. The Anyue gas fields, with recently discovered proven reserves of more than 8000 × 10^8 m^3, are also distributed in dolomite reservoirs in the Sinian Dengying Formation and Cambrian Longwangmiao Formation. The deeply-buried Ordovician oil and gas resources in the Ordos Basin are also concentrated in dolomite reservoirs. The Cambrian Sarbulak Formation in the Tarim Basin has a considerable exploration potential in Sarbulak Formation dolostone. The exploration of deeply-buried dolomite reservoirs in the cratonic basins is promising. This paper intends to point out the controlling factors in regards to the formation and distribution of deeply-buried high-quality reservoirs through characterization and genesis analysis. This study aims to provide references for oil and gas exploration in deeply-buried dolomite reservoirs in major cratonic basins such as the Sichuan, the Tarim Basin, and the Ordos Basin in China.

2. Deep dolomite reservoirs in cratonic basins

2.1. Reservoir rock

Deeply-buried carbonate rocks in cratonic basins are of various types. Statistics of more than 4000 blocks in the Sichuan Basin, the Ordos Basin, and the Tarim Basin shows that the reservoirs are mainly developed in granular dolomite, algae (including cyanobacteria) dolomite, and crystalline dolomite (Fig. 1).

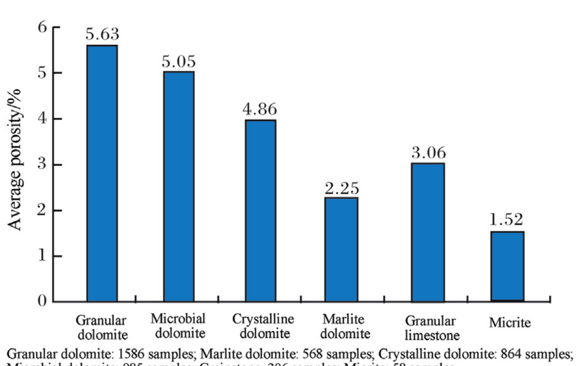

Fig. 1. Average porosity of deeply-buried carbonate rocks.

Different types of deeply-buried carbonate rocks in the Sichuan Basin, the Ordos Basin, and the Tarim Basin are classified into six categories: granular dolomite, microbial dolomite, crystalline dolomite, muddy dolomite, granular limestone, and marlite. It should be noted that some transitional rocks are classified into these six categories, such as lime grain dolomite into granular dolomite and dolomitic grain limestone into granular limestone.

(1) Granular dolomite includes granulose dolomite, bioclastic dolomite, and residual granitoids with grain phantoms after diagenetic alteration and lime dolomite. Pores in these rocks are mainly intergranular and intragranular solution pores, as well as intercrystalline pores (Fig. 2a and b).
(2) Microbial dolomite: Different scholars have different classifications of microbial dolomite. In our data, "microbial dolomite" involves the Sinian dolomite in the Sichuan Basin, the Ordovician dolomite in the Ordos Basin, and the Ordovician dolomite in the Tarim Basin. They are related to algae, such as algae-angulated dolomite, algae dolomite, and algal-layer dolomite. Pores in these rocks are solution skeletal and fenestra pores (Fig. 2c and d).
(3) Crystalline dolomite: In this process, the strong recrystallization created powdery to coarse crystals. Conventional techniques cannot identify the original rock structure or illusion. It is also here where intercrystalline pores are developed (Fig. 2e and f).
(4) Marlite dolomite: It refers to dolomite that has undergone weak diagenesis and has no granular structure and microbiological characteristics. Pores are not developed in most marlite dolomites, but gypsum molded pores are formed in the marlite dolomite with developed gypsum nodules (Fig. 2g and h).
(5) Granular limestone: It consists of granular limestone and bioclastic limestone. Most deeply-buried granular limestones are strongly cemented, resulting in tight rocks. However, intragranular solution pores are developed locally (Fig. 2i and j).
(6) Marlite: It refers to the limestone with weak diagenesis with no granular structure and microbiological characteristics. In this paper, the sparry limestone without granular structure is classified under this type.

2.2. Pore types

Thin sections and cores of deeply-buried dolomites show two types of reservoir space: pore-type, and pore-vug-type (Fig. 3a—d). The pore-type dolomite, dominated by matrix pores, includes intergranular pores, celom pores, and molded pores. The pore-vug-type dolomite contains expanded matrix pores larger than 2 mm. Statistics (Fig. 3e) indicates that the permeability and porosity of the pore-vug-type dolomite have an excellent correlation to each other (yellow lines in Fig. 3c and e). The pore-vug-type dolomite is of higher porosity (red lines in Fig. 3a, d, and e). Additionally, the development of fracture-type reservoir can be observed (green lines in Fig. 3b and e).

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